



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF A PATH LOSS MODEL FOR WAVE  
PROPAGATION INTO SELECTED BUILDINGS AT UNIVERSITI  
PUTRA MALAYSIA**

**MARDENI HJ. ROSLEE.**

**ITMA 2005 3**

**DEVELOPMENT OF A PATH LOSS MODEL FOR WAVE PROPAGATION  
INTO SELECTED BUILDINGS AT UNIVERSITI PUTRA MALAYSIA**

**By**

**MARDENI HJ. ROSLEE**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia  
In Fulfilment of the Requirements for the Degree of Master of Science**

**May 2005**



## **DEDICATION**

**Specially dedicated to:**

**My beloved**

**Father, Mother,**

**Brother, Sisters,**

**Soul mate,**

**and Friends.**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

**DEVELOPMENT OF A PATH LOSS MODEL FOR WAVE PROPAGATION  
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**May 2005**

**Chairperson : Zulkifly Abbas, PhD**

**Institute : Advanced Technology**

In this thesis, the development of path loss prediction model for wave propagation into buildings at Universiti Putra Malaysia is described. Field strength measurements due to three base stations were carried out in three different buildings in the Universiti Putra Malaysia campus. The measurement setup consisted of an ADVANTEST U3641 Spectrum Analyzer and an AHS/SAS-519-4 log periodic antenna. A computer program has been developed to calculate the path loss from the measured field strength which in turn was used for comparison with available path loss models. The results indicate poor agreement between the measured and existing predicted path loss models where even the widely accepted COST 231 model deviated as high as 9.46%. The discrepancy between the measured and predicted path loss was even greater for other models such as the Microcell model (17.69%) and outdoor-indoor model (24.71%). An improved version of COST 231 model and an empirical path loss models have been proposed in this work to

replace the COST 231 model. The improved COST 231 model was found from an optimization procedure by fitting the original model to the measured data, whilst the empirical model was obtained from regression analysis. The accuracy of the Improved COST 231 and empirical models was tested on different buildings and found to agree with measured data within 6.31%, and 7.85%, respectively. The Agilent VEE software was used to develop and execute the integrated ITMAPL program for wave propagation into buildings. The ITMAPL program is a user friendly program to calculate and display the path loss of radio propagation paths. It is implemented in the run time format version and has three options which are COST 231 model (CST), improved COST 231 model (ICS) and ITMANE new empirical model.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PEMBINAAN MODEL KEHILANGAN LINTASAN BAGI RAMBATAN  
GELOMBANG KE DALAM BANGUNAN YANG DIPILIH DI UNIVERSITI  
PUTRA MALAYSIA**

Oleh

**MARDENI HJ. ROSLEE**

**Mei 2005**

**Pengerusi : Zulkifly Abbas, PhD**

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Dalam tesis ini, pembinaan model untuk meramal kehilangan lintasan bagi rambatan gelombang ke dalam bangunan di Universiti Putra Malaysia akan diperihalkan. Kekuatan medan magnet dari tiga stesen punca telah dilakukan pada tiga bangunan yang berlainan di kawasan kampus Universiti Putra Malaysia. Alat pengukuran yang digunakan adalah Penganalisis Spektrum ADVANTEST U3641 dan Antena Berkala AHS/SAS-519-4. Satu program komputer telah dicipta untuk mengira nilai kehilangan lintasan daripada nilai pengukuran medan magnet di mana nilai ini digunakan untuk membuat perbandingan dengan nilai kehilangan lintasan yang sedia ada. Keputusan yang diperolehi menunjukkan ketidaksamaan antara nilai ukuran dan juga model kehilangan lintasan yang sedia ada walaupun model COST 231 menyisih sebanyak 9.46%. Penyisihan antara nilai ukuran dan juga ramalan kehilangan lintasan lebih tinggi bagi model yang lain seperti model microcell (17.69%) dan model outdoor-indoor

(24.71%). Versi model COST 231 yang diperbaharui dan juga model empirikal telah dicadangkan di dalam kerja ini untuk menggantikan model COST 231 yang asal. Model COST 231 yang diperbaharui diperolehi daripada presedur pengotimuman dengan menyesuaikan nilai ukuran dengan model asal. Model empirikal pula diperolehi daripada analisis regresi. Ketepatan model COST 231 yang diperbaharui dan model empirikal telah diuji pada bangunan yang berlainan dan telah menepati nilai data ukuran dengan nilai perbezaan 6.31% dan 7.83% masing-masing. Perisian Agilent VEE telah digunakan dalam pembinaan dan pelaksanaan program penggabungan kehilangan lintasan Institut Teknologi Maju (ITMAPL) untuk rambatan gelombang ke dalam bangunan. Program ITMAPL ini adalah program yang mudah digunakan untuk mengira dan menunjukkan nilai kehilangan lintasan bagi rambatan gelombang radio. Ianya dilaksanakan dalam versi format run time dan mengandungi tiga pilihan iaitu model COST 231 (CST), model COST 231 yang diperbaharui (ICS) dan juga model empirikal yang baru ITMANE.

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Wassalam.



I certify that an Examination Committee met on 25<sup>th</sup> May 2005 to conduct the final examination of Mardeni Hj. Roslee on his Master of Science thesis entitled “Development of a Path Loss Model for Wave Propagation into Selected Buildings at Universiti Putra Malaysia” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



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**MARDENI HJ.ROSLEE**

Date: 18.7.05

## TABLE OF CONTENTS

|                              | Page |
|------------------------------|------|
| <b>DEDICATION</b>            | ii   |
| <b>ABSTRACT</b>              | iii  |
| <b>ABSTRAK</b>               | v    |
| <b>ACKNOWLEDGEMENTS</b>      | vii  |
| <b>APPROVALS</b>             | viii |
| <b>DECLARATION</b>           | x    |
| <b>LIST OF TABLES</b>        | xiii |
| <b>LIST OF FIGURES</b>       | xiv  |
| <b>LIST OF ABBREVIATIONS</b> | xvii |

## CHAPTER

### 1 INTRODUCTION

|     |  |   |
|-----|--|---|
| 1.1 | Introduction to Wireless Communication Systems | 1 |
| 1.2 | Concept of a Wireless Channel                  | 3 |
| 1.3 | The Electromagnetic Spectrum                   | 4 |
| 1.4 | Indoor Propagation Prediction Models           | 6 |
| 1.5 | Objectives in Project                          | 8 |
| 1.6 | Scope of thesis                                | 8 |

### 2 AN OVERVIEW OF WAVE PROPAGATION INTO BUILDINGS

|       |                                   |    |
|-------|-----------------------------------|----|
| 2.1   | Propagation Mechanism             | 9  |
| 2.2   | Signal Penetration into Buildings | 11 |
| 2.3   | Path Loss Models                  | 12 |
| 2.3.1 | COST 231 Model                    | 13 |
| 2.3.2 | Outdoor-Indoor Model              | 14 |
| 2.3.3 | Microcell Model                   | 15 |
| 2.4   | Lognormal Distribution            | 16 |
| 2.4.1 | Probability Density Function      | 16 |
| 2.4.2 | Rayleigh Distribution             | 17 |

### 3 PROPAGATION MEASUREMENTS

|       |                            |    |
|-------|----------------------------|----|
| 3.1   | Field Profile Measurements | 18 |
| 3.1.1 | Measurement Procedure      | 18 |
| 3.1.2 | Measurement Location       | 19 |
| 3.1.3 | Base Station               | 20 |
| 3.2   | Measurement System Setup   | 24 |
| 3.2.1 | Calibrated Data            | 26 |
| 3.2.2 | Data Acquisition           | 27 |



|          |  |     |
|----------|--|-----|
| 3.3      | Calculation of Path Loss                                 | 32  |
| <b>4</b> | <b>RESULTS AND DISCUSSION</b>                            |     |
| 4.1      | Measurement Results                                      | 34  |
| 4.1.1    | Analysis of Measurement Taken in BA                      | 34  |
| 4.1.2    | Analysis of Measurement Taken in BB                      | 58  |
| 4.1.3    | Analysis of Measurement Taken in BC                      | 72  |
| 4.2      | Uncertainties Analysis of Path Loss Models               | 88  |
| 4.2.1    | Path Loss Models Uncertainties Due to the Distance, $S$  | 88  |
| 4.2.2    | Path Loss Models Uncertainties Due to the Distance, $D$  | 89  |
| 4.2.3    | Path Loss Models Uncertainties Due to the Frequency, $f$ | 90  |
| 4.3      | ITMAPL Program Development                               | 93  |
| 4.3.1    | CST Model Option   | 93  |
| 4.3.2    | ITMANE Model Option                                      | 94  |
| 4.3.3    | ICS Model Option   | 95  |
| <b>5</b> | <b>CONCLUSION AND SUGGESTION</b>                         |     |
| 5.1      | Conclusions  | 101 |
| 5.2      | Main Contributions                                       | 102 |
| 5.3      | Suggestions for Future work                              | 103 |
|          | <b>REFERENCES</b>  | 105 |
|          | <b>BIODATA OF THE AUTHOR</b>                             | 108 |

## **LIST OF TABLES**

| <b>Table</b>  | <b>Page</b> |
|---|-------------|
| 1.1 The electromagnetic spectrum  | 5           |
| 1.2 Identification conventions for frequency bands  | 5           |
| 2.1 Wall attenuation in different materials for Microcell model   | 16          |
| 3.1 The characteristics for each base station that used in measurement  | 20          |
| 4.1 Measurements path with distances for ground floor and first floor, BA1, BA2 and BA3                                       | 40          |
| 4.2 Dimension of parameters in Building complex A   | 40          |
| 4.3 Mean values and standard deviation of field strength signal in building A   | 43          |
| 4.4 Mean error between measurements and models in building A  | 49          |
| 4.5 Mean error between measured path loss and I.COST 231, COST 231 and Empirical models<br>(a): building B<br>(b): building C | 55          |
| 4.6 Measurements path with distances for ground floor and first floor, BB1, BB2 and BB3                                       | 62          |
| 4.7 Dimension of parameters in building complex B   | 62          |
| 4.8 Mean values and standard deviation of field strength signal in building B   | 64          |
| 4.9 Mean error of path loss between measurements and models in building B   | 70          |
| 4.10 Measurements path with distances for ground floor and first floor, BC1, BC2 and BC3                                      | 78          |
| 4.11 Dimension of parameters in Building complex C  | 78          |
| 4.12 Mean values and standard deviation of field strength signal in building C  | 80          |
| 4.13 Mean error between measurements and models in building C   | 86          |

## LIST OF FIGURES

| Figure  | Page |
|---|------|
| 2.1 (a) Refection, (b) Diffraction, (c) Guided wave   | 10   |
| 2.2 Wall layout at one single floor in the building for COST 231 model  | 13   |
| 2.3 (a) Probability Density Function (b) Experimental Rayleigh Distribution   | 17   |
| 3.1 FSAS Base station   | 21   |
| 3.2 MSC Tower base station  | 22   |
| 3.3 UPM Campus base station   | 22   |
| 3.4 Map of the measurement environment from three base stations toward three buildings in UPM                                     | 23   |
| 3.5 (a) Measurement setup<br>(b) Magellan Meridian Global Positioning System unit (GPS)   | 24   |
| 3.6 Flow diagram in measurements process to develop model   | 25   |
| 3.7 The main panel of Geographic Coordinate (GC) software.  | 26   |
| 3.8 The main panel for collection of data from acquisition of measurement by control the spectrum analyzer with personal computer | 30   |
| 3.9 Field strength in dB $\mu$ V/m unit in 'file 74.txt'.   | 32   |
| 4.1 In front of a) BA1 b) BA2   | 35   |
| 4.2 Corridor in first floor of a) BA1 b) BA2  | 35   |
| 4.3 In front of BA3   | 36   |
| 4.4 Corridor in BA3 a) ground floor b) first floor  | 36   |
| 4.5 The layout plan of building complex A: BA1, BA2 and BA3   | 37   |
| 4.6 Plan of BA1 and BA2 a) ground floor b) first floor  | 38   |
| 4.7 Plan of BA3 a) ground floor b) first floor  | 39   |

|      |   |    |
|------|---|----|
| 4.8  | Variation in received signal strength with distance in building A<br>(a) BA1<br>(b) BA2<br>(c) BA3        | 45 |
| 4.9  | Probability density function of received signal strength in building A<br>(a) BA1<br>(b) BA2<br>(c) BA3   | 47 |
| 4.10 | Comparison between measurement (Path Loss) and Models taken in building A between 3 different frequencies | 50 |
| 4.11 | Comparison between measured path loss and COST 231, I.COST 231 and Empirical models for building B        | 56 |
| 4.12 | Comparison between measured path loss and COST 231, I.COST 231 and Empirical models for building C        | 57 |
| 4.13 | Entrance of building B  | 58 |
| 4.14 | Corridor in first floor, BB1  | 58 |
| 4.15 | Corridor in ground floor, BB1   | 59 |
| 4.16 | Corridor in first floor of BB1  | 59 |
| 4.17 | The layout plan of building complex B: BB1, BB2 and BB3   | 60 |
| 4.18 | Plan of building complex B: (a) ground floor (b) first floor  | 61 |
| 4.19 | Variation in received signal strength with distance in building B<br>(a) BB1<br>(b) BB2<br>(c) BB3        | 66 |
| 4.20 | Probability density function of received signal strength in building B<br>(a) BB1<br>(b) BB2<br>(c) BB3   | 68 |
| 4.21 | Comparison between measurement (Path Loss) and Models taken in building B between 3 different frequencies | 71 |
| 4.22 | Front view of building C  | 73 |



|      |   |     |
|------|---|-----|
| 4.23 | Side view of the BC1  | 73  |
| 4.24 | Corridor in first floor, BC1  | 73  |
| 4.25 | Corridor in ground and first floor, BC2   | 74  |
| 4.26 | Corridor in ground floor, BC2   | 74  |
| 4.27 | Corridor in ground floor, BC3   | 75  |
| 4.28 | Corridor in first floor, BC3  | 75  |
| 4.29 | The layout plan of building complex C: BC1, BC2 and BC3   | 76  |
| 4.30 | Plan of building complex C: (a) ground floor (b) first floor  | 77  |
| 4.31 | Variation in received signal strength with distance in building C<br>(a) BC1<br>(b) BC2<br>(c) BC3            | 82  |
| 4.32 | Probability density function of received signal strength in building C<br>(a) BC1<br>(b) BC2<br>(c) BC3       | 84  |
| 4.33 | Comparison between measurement ( Path Loss) and Models taken<br>in building C between 3 different frequencies | 87  |
| 4.34 | Path loss uncertainties with distance, $S$ uncertainties  | 89  |
| 4.35 | Path loss uncertainties with distance, $D$ uncertainties  | 90  |
| 4.36 | Path loss uncertainties with frequencies, $f$ uncertainties   | 92  |
| 4.37 | Flow chart of the ITMAPL program with conditions  | 96  |
| 4.38 | The main panel of the main menu for ITMAPL program  | 97  |
| 4.39 | The main panel of the CST option for ITMAPL program   | 98  |
| 4.40 | The main panel of the ITMANE option for ITMAPL program  | 99  |
| 4.41 | The main panel of the ICS option for ITMAPL program   | 100 |

## LIST OF ABBREVIATIONS

|               |   |  |
|---------------|---|--|
| $L$           | - | Path Loss Total  |
| $f$           | - | Frequency  |
| $S$           | - | Physical distance between external transmitter and external wall       |
| $d$           | - | Perpendicular distance between internal walls and external walls       |
| $d_2$         | - | Distance between measured point and origin point                       |
| $W_e$         | - | Loss in external walls   |
| $W_{Ge}$      | - | Additional loss in external walls                                      |
| $D$           | - | Perpendicular distance between external transmitter and external walls |
| $W_i$         | - | Loss in the internal walls   |
| $\theta$      | - | Grazing angle  |
| $dB$          | - | Decibels   |
| $m$           | - | meter  |
| $dBm$         | - | Decibels refer to 1 miliWatt   |
| $dB\mu V / m$ | - | Decibels micro volt per meter  |
| $dBW$         | - | Decibels watt  |
| $dBi$         | - | Decibels refer to isotropic  |
| $p$           | - | Number of penetrated walls   |
| $Lw_e$        | - | Loss in external walls   |
| $Lw_i$        | - | Loss in internal walls   |

|                    |   |  |
|--------------------|---|--|
| $N$                | - | Number of measured data                |
| $x$                | - | Measured data points                   |
| $x_L$              | - | Predicted model value                  |
| $\bar{x}$          | - | Mean of measured data points           |
| $\sigma$           | - | Standard deviation                     |
| $\pi$              | - | pi                                     |
| $Y$                | - | Received signal                        |
| $p(Y)$             | - | Normal distribution of signal strength |
| $\alpha_Y$         | - | Standard deviation of signal strength  |
| $\alpha_Y^2$       | - | Variances of signal strength           |
| $M_Y$              | - | Mean of signal strength                |
| $P$                | - | Field Strength                         |
| $E$                | - | Measurement value                      |
| $G_r$              | - | Isotropic gain of receiving antenna    |
| $P_r$              | - | Received power                         |
| $P_t$              | - | Transmit power                         |
| <i>lsqcurvefit</i> | - | Least square curve fitting             |
| $\Delta L$         | - | Uncertainties in path loss             |
| $\Delta S$         | - | Uncertainties in distance 1            |
| $\Delta D$         | - | Uncertainties in distance 2            |
| $\Delta f$         | - | Uncertainties in frequency             |
| P.D.F              | - | Probability Density Function           |

|               |   |   |
|---------------|---|---|
| <b>C.D.F</b>  | - | <b>Cumulative Distribution Function</b>               |
| <b>GPS</b>    | - | <b>Global positioning system</b>                      |
| <b>MATLAB</b> | - | <b>Matrix laboratory</b>                              |
| <b>BA</b>     | - | <b>Building complex A</b>                             |
| <b>BB</b>     | - | <b>Building complex B</b>                             |
| <b>BC</b>     | - | <b>Building complex C</b>                             |
| <b>GC</b>     | - | <b>Geometry Coordinate</b>                            |
| <b>IP</b>     | - | <b>Execute the master reset</b>                       |
| <b>AV</b>     | - | <b>View the measurement data</b>                      |
| <b>CF</b>     | - | <b>Center frequency</b>                               |
| <b>SP</b>     | - | <b>Frequency span</b>                                 |
| <b>MKR</b>    | - | <b>Marker frequency</b>                               |
| <b>ML</b>     | - | <b>Marker level</b>                                   |
| <b>READ</b>   | - | <b>Read data from measurement</b>                     |
| <b>ITMAPL</b> | - | <b>Institute of Advanced Technology Path Loss</b>     |
| <b>CST</b>    | - | <b>COST 231</b>                                       |
| <b>ITMANE</b> | - | <b>Institute of Advanced Technology New empirical</b> |
| <b>ICS</b>    | - | <b>Improved COST 231</b>                              |
| <b>MS</b>     | - | <b>Mobile system</b>                                  |
| <b>BS</b>     | - | <b>Base station</b>                                   |
| <b>NLOS</b>   | - | <b>Non line of sight</b>                              |
| <b>LOS</b>    | - | <b>Line of sight</b>                                  |
| <b>VEE</b>    | - | <b>Visual Environment Engineering</b>                 |
| <b>RF</b>     | - | <b>Radio frequency</b>                                |

|              |   |  |
|--------------|---|--|
| <b>GSM</b>   | - | <b>Global System Mobile</b>                    |
| <b>UHF</b>   | - | <b>Ultra High Frequency</b>                    |
| <b>SHF</b>   | - | <b>Super High Frequency</b>                    |
| <b>EHF</b>   | - | <b>Extra High Frequency</b>                    |
| <b>VHF</b>   | - | <b>Very High Frequency</b>                     |
| <b>VLF</b>   | - | <b>Very Low Frequency</b>                      |
| <b>LF</b>    | - | <b>Low Frequency</b>                           |
| <b>MF</b>    | - | <b>Medium Frequency</b>                        |
| <b>HF</b>    | - | <b>High Frequency</b>                          |
| <b>COST</b>  | - | <b>Co-operation Scientific Technical</b>       |
| <b>NTT</b>   | - | <b>Nippon Telegraph and Telephone</b>          |
| <b>JTACS</b> | - | <b>Japan Total Access Communication System</b> |
| <b>NMT</b>   | - | <b>Nordic Mobile Telephone</b>                 |
| <b>AMPS</b>  | - | <b>Advanced Mobile Phone Systems</b>           |
| <b>TACS</b>  | - | <b>Tactical Area Communications System</b>     |
| <b>USDC</b>  | - | <b>United States Path Capture</b>              |
| <b>DECT</b>  | - | <b>Digital European Cordless Transmission</b>  |
| <b>DCS</b>   | - | <b>Defense Communication Systems</b>           |
| <b>PHS</b>   | - | <b>Personal Handyphone System</b>              |
| <b>CDMA</b>  | - | <b>Code Division Multiple Access</b>           |
| <b>TDMA</b>  | - | <b>Time Domain Multiple Access</b>             |

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction to Wireless Communication Channel**

Communication in fixed links providing telephone service has been established since 1940 while satellite links are being used for intercontinental communication since 1960s. The idea of wireless communication begun when Maxwell predicted the existence of electromagnetic waves in 1873 followed by Hertz who demonstrated the radio waves in 1888 (Saunders, 1999).

In 1945, Clarke proposed geostationary communications satellites followed by launching of Sputnik 1 communication satellite by Soviet Union in 1957. In 1969, Bell Laboratories (US) invented the cellular concept and followed by NTT (1979) and JTACS (1988) cellular system in Japan. Then, it was continued by NMT in Scandinavia (1981), AMPS cellular frequencies allocated in US (1983), TACS in Europe (1985) and USDC in US (1991). In Europe (1991), the GSM cellular system was deployed followed by DECT and DCS (1993) while PHS cordless system was deployed in Japan in the same year. IS95 CDMA was introduced in US (1995) continued by the launching of Iridium global satellite system in 1998 and IMT-2000 third generation cellular mobile systems was deployed in 2002.

Before mid 1960s, research of mobile radio to fulfill the specific operational and economic needs was a minor action in terms of international scale even though the demand for mobile radio services was continuously increased. Since the existing systems had reached the development limit that can support the technology that time, the strategic research was justified and it obviously results in most of the developed countries. After that, it was apparently seen that the contribution in mobile radio has affected the national economy by the use of pocket radios, hand-held and vehicle-borne transceivers and pan-European digital systems using wideband TDMA techniques.

The research activities mainly involved characterization and modeling of radio propagation channel which are the principle contributor to problems and limitations occurred in mobile radio systems such as multipath propagation. The multipath propagation is a main characteristic of mobile channel caused by diffraction and scattering from terrain features and buildings. This leads to distortion in analogue communication systems and severely affects the performance of digital systems by reducing the carrier-to-noise and carrier-to-interference ratios.

Nowadays, cellular mobile communications industry becomes one of the fastest-growing industries with a great number of users increased rapidly. This has resulted in stimulation of financial investment in such systems as well as to the rise of a large number in technical challenges which required a deep understanding on the characteristics of the wireless channel for their solution.

## **1.2 Concept of a Wireless Channel**

The study of wireless channel is an important element of the operation, design and analysis of any wireless system such as cellular mobile phones or mobile satellite systems. The design of generic communication system was originally presented by Claude Shannon of Bell Laboratories in his classic 1948 paper (Shannon, 1948). The generic communication system is used for all types of systems which are wireless or otherwise. In wireless channel, fading is considered to be one of the main causes of performance degradation in a mobile radio system. If fading is taken into account, it would affect the data transmission. There are three types of fading; path loss, shadowing or slow fading and fast fading or multi path fading. They are appearing as time-varying processes between the transmitter and receiver. It also varies with the relative position of both antennas (Saunders, 1999).

The fading processes presented the mobile receiver received the signal that moving away from the base station. Normally, the path loss is decreased in field strength with increasing distance between the transmitter and receiver. This phenomenon is due to the external distribution of waves from the transmitter and obstructing effects of buildings. Furthermore, the shadowing which is a superimposed on the path loss changes faster with large variations over distances of hundreds of meters and generally involving variations up to around 20 dB. It arises from the varying nature of the exacting obstructions between both antennas. Besides, the fast fading involves variations on the scale of a half-wavelength, about 50 cm at 300 MHz, 17 cm at 900 MHz and frequently introduces variations as large as 35 to 40 dB. The last results are from the beneficial and



critical interference between multiple waves reaching the receiver from the transmitter. The total signal is the combinations of path loss, shadowing and fast fading.

### **1.3 The Electromagnetic Spectrum**

The electromagnetic spectrum is an essential resource demoralized in wireless communication systems as seen in Table 1.1. From the figure, the frequencies around 3 kHz to 300 GHz is for radio communication where it corresponds to wavelengths in free space from 100 km to 1 mm. The conventional division of the spectrum into frequency bands is defined as in Table 1.2 from 3 kHz to 300 GHz. A further subdivision creates the UHF, SHF and lower EHF bands (Saunders, 1999).

The demand for wireless communication as the frequencies chosen for new systems have tended to enhance through the years due to the availability of huge bandwidths at the higher frequencies. The change has formed the technology challenges needed to support reliable communications as the advantage of antenna structures can be smaller in absolute size to support a given level of performance. This study will only be concerned in communication at VHF frequencies and above. The wavelength is typically small compared with the size of macroscopic obstructions like buildings. As the size of obstructions relative to a wavelength increases, their obstructing effects also tend to increase, reducing the range for systems operated at increasing frequencies.